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OPTIMIZATION OF HARD PART TURNING OF BOHLER K 110 STEEL WITH MULTIPLE PERFORMANCE CHARACTERISTICS USING GREY RELATIONAL ANALYSIS

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ABSTRACT

Böhler K110material is used in High-duty cutting tools, blanking and punching tools& small moulds for the plastics industry where excellent wear resistance is required. It is difficult to machine the material in the hardened state (58 HRc).

This paper presents the optimization of surface roughness &tool wear in hard part turning (HPT) of Bohler K110 steel. Uncoated Carbide inserts were used for machining of Bohler K110 to study effects of process parameters [Cutting speed (S), Feed (F) and depth of cut (D)].Grey Relational analysis is used to optimize the multi performance characteristics to minimise the surface roughness and tool wear.

Keywords: Speed (S), Feed (F), Depth of cut (d),Hard Part Turning (HPT), Bohler K110, Grey Relational Analysis.

1. INTRODUCTION

Turning steel with a hardness over 48 HRc (typically within the range of 55-68 HRc) is defined as hard part turning (HPT) and is a cost efficient alternative to grinding. Hard part turning has been proven to reduce machining time and costs by 70% or more, and also offers improved flexibility, better lead times and higher quality.

In micro, small and medium industries (MSME) industries, the technology is replacing grinding – cutting costs and raising productivity accordingly. The advent of super-hard cutting tool materials such as cubic boron nitride (CBN) and aluminium oxide ceramics, plus new optimized

machines, makes HPT a viable manufacturing process for mass production. Today, HPT is well accepted and well able to meet industry productivity goals of higher quality and shorter cycle times. In the automotive industry, HPT is especially competitive. Increased demands for improved productivity and cost efficiency have driven the turning of many components in the hardened state. Manufacturers now design these components for HPT rather than grinding.

As a single-point contact method, HPT can easily accomplish complex contours without need for the costly form wheels that multi-point contact grinding requires. Similarly, HPT permits machining of multiple operations with just one set-up. The result is excellent positional accuracy, reduced part handling and less risk of part damage. The environment also benefits from HPT as the technique eliminates grinding waste and does not require coolant. All in all, HPT reduces machine tool costs and gives better production control, quicker throughput and higher quality. These plus points together and the cost-savings brought about by switching to HPT are considerable.

Surface roughness is a factor which is influential in the manufacturing cost. The surface roughness describes the geometry of the machined surfaces coupled with surface texture. Optimization of machining parameters like tool life, surface roughness, cutting force, material removal is significant for increased productivity. Among these four characteristics, surface roughness and tool wear play the most important roles in the performance of a turning process. Cutting speed, feed rate, depth of cut, tool-work piece material, tool geometry, and coolant conditions are the turning parameters which highly affect the performance measures. In order to improve machining efficiency, reduce the machining cost, and improve the quality of machined parts, it is necessary to select the most appropriate machining conditions.

Micro, small & medium industries (MSME) in India have made very great progress in-spite of limited resources impacting on occupational health & safety [13], also main drawback with MSME industries is the attainment of the optimum operating parameters of the machines. It has long been recognized that conditions during cutting such as feed rate, depth of cut, cutting speed should be selected to optimize the economics of machining operations. In machine tool field turning is valuable process. A major factor leading to the use of turning in place of grinding has been the development of cubic boron nitride (CBN) cutting tool insert, which enable machining of high-strength materials with a geometrically defined cutting edge.

2. LITERATURE REVIEW

The experimental investigations conducted by Sahoo and Sahoo (2012) investigated flank wear, surface roughness, chip morphology and cutting forces in hard turning of AISI 4340 steel (47 HRC); using uncoated and multilayer TiN and ZrCN coated carbide inserts. Experimental results showed that multilayer TiN/TiCN/Al2O3/TiN coated carbide inserts performed better than the uncoated and TiN/TiCN/ Al2O3/ZrCN coated carbide inserts [1].Asiltürk and Akkus (2011) focused on optimizing turning parameters based on the Taguchi method to minimize surface roughness by using hardened AISI 4140 (51 HRC) with coated carbide cutting tools. Results of this study indicate that the feed rate has the most significant effect on surface roughness.In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. [2]. Kumbhar investigated tool life and surface roughness optimization of PVD TiAlN/TiN coated carbide inserts in semi hard turning of hardened EN31 alloy steel under dry cutting conditions using Taguchi method. They have concluded that the feed rate was the most influential factor on the surface roughness and tool life. [3].Investigations conducted by Lima et al (2005) turning of AISI D2 steel (58 HRC) with mixed alumina inserts allowed a surface finish as good as that produced by cylindrical grinding [4]. Chinchanikar and Choudhary (2013) investigated that cutting speed followed by depth of cut was found to be most influencing factors on tool life especially when turning harder work piece. [5]. Davim and figueira (2007) Machinability evaluation

in hard turning of cold work (D2) using ceramic tools finds that tool wear if highly influenced by cutting velocity and cutting time [6].Gaitonde et al (2009) experimented that the tool wear decreases with increase in depth of cut upto 0.4 mm and then suddenly increase in the case of CC650 & CC650 WH inserts [7].Choudhury and Appa Rao (1999) presented a new approach for improving the cutting tool life by using optimal values of velocity and feed throughout the cutting process. The experimental results showed an improvement in tool life by 30% [8].Dilbag Singh and P. Venkateswara Rao(2007) with mixed ceramic inserts made up of aluminium oxide and titanium carbon nitride (SNGA) exhibited the effect of cutting conditions and tool geometry on surface roughness in finished hard turning of bearing steel (AISI 52100). The primary influential factors that affect the surface finish are cutting velocity, feed, effective rake angle and nose radius [9].Abhang (2011) have created model and analyzed it for surface roughness in machining EN 31 steel using response surface methodology. They have found that surface roughness increases with increase in feed rate and decreases with increase in cutting velocity[10].Raykar and D.M.D'Addona (2014) et al investigated that regression models can be effectively used to predict the surface roughness within the specified range of cutting parameters [11].Desale and Jahagirdar (2012) reported that in End milling process of Bohler K110, feed rate is most impacting factor on work piece surface roughness followed by spindle speed and depth of cut. [12].

Satyanarayana et al. used taguchi based grey relational analysis on optimized high speed turning of Inconel 718[14].

A.D.Jewalikar et al concluded in the experiments for Hard Part Turning of Bohler K110 material in dry machining. For Surface Roughness (Ra) Cutting speed is the dominant factor followed by feed and depth of cut [15].

From the Literature Review it is observed that very few works are reported on hardened steel material like Böhler K110.This material is used in High-duty cutting tools, blanking and punching tools, wood working tools, shear blades for cutting light gauge material, thread rolling tools, tools for drawing, deep drawing and cold extrusion, pressing tools for the ceramics and pharmaceutical industries, cold rolls & stands, measuring instruments and gauges, and small moulds for the plastics industry where excellent wear resistance is required.

3. GREY RELATIONAL ANALYSIS

The grey relational analysis (GRA) represents a rather new approach to optimization. The grey theory is based on the random uncertainty of small samples whichdeveloped into an evaluation technique to solve certain problems of system that are complex and having incomplete information. A system for which the relevant information is completely known is a 'white' system, while a system for which the relevant information is completely unknown is a 'black' system. Any system between these limits is a 'grey' system having poor and limited information [18].Grey relational analysis (GRA), a normalized evaluation technique, is extended to solve the complicated multi performance characteristics optimization effectively.

The optimization of multiple performance characteristics is different from that of a single performance characteristic. The higher S/N ratio for one performance characteristic may correspond to a lower S/N ratio for another. Therefore, the overall evaluation of the S/N ratio is required for the Optimization of multiple performance characteristics. The usual recommendation for the optimization of a process with multiple performance characteristics is left to the engineering judgment and verified by confirmation experiment [17]. The grey system theory proposed by Deng has been proven to be useful for dealing with poor, incomplete and uncertain information.

The first step of the grey relational analysis is the grey relational generation [18]. During this step, all the performance characteristics are normalized in the range between zero and one. Next, the grey relational coefficient is calculated from the normalized data to express the relationship between

the desired and actual normalized performance values. Then, the grey relational grade is computed by assigning a suitable weighting factor (in percent) to the grey relational coefficient corresponding to each performance characteristic. Overall evaluation of the multiple performance characteristics is, thus, based on the grey relational grade. As a result, optimization of the complicated multiple performance characteristics can be converted into optimization of a single grey relational grade.
The optimal level of the process parameters is the level with the highest grey relational grade. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the analysis.

4. EXPERIMENTAL CONDITION

Many factors affect the surface roughness in turning process. The important machining parameters include feed rate (F), depth of cut (D) and cutting speed (S).

Table 1. Chemical Composition of Böhler K110

C	Si	Cr	Mn	Mo	V
1.55	0.30	11.30	0.30	0.75	0.75

Experimental work was carried out on CNC turning machine (HAAS). A round bar (ø 91 mm × L 50 mm) of Böhler K110 steel was turned for each parameter combination tested. The cutting was performed by using turning inserts (CNGA 120408 THM) by WIDIA uncoated insert which could provide higher heat resistance, under dry conditions. The objective of the experiments was to secure the advantageous outcomes such as minimum surface roughness, less heat generation, minimum tool wear, and better geometrical accuracy. Measurements of surface roughness were conducted in order to characterize the process and determine the optimal operation conditions. For every operation a cut of 35 mm was taken. Also for every operation new insert was used. After each cut, the surface roughness was measured on the surface table with the help of surface roughness tester (Taylor Hobson) having cut off length 0.8 mm and evaluation length 25 mm. Three spots on each turned work piece were used to measure the surface roughness of the cut.

Table 2. Experimental Parameters & their Levels

Independent Variables	Level I	Level II	Level III
Cutting Speed (v) (m/min)(X_1)	80	105	130
Feed (f) (mm/rev) (X_2)	0.2	0.35	0.5
Depth of cut (d) (mm) (X_3)	0.5	0.75	1.0

Table 3. Experimental conditions

Machine tool	CNC (HAAS) Turning Machine SL-20 (7.5hp, 5.6 Kw)
Materials	Premium Bohler K110 steel
Hardness	58 HRC
Size of work piece	Dia 91 mm x 50 mm
Cutting tool Holder	PCLNL2525M12
Cutting Insert	CNGA 120408 THM
Cutting parameters	
Cutting velocity	80-130 mm/min
Feed rate	0.2 to 0.5 mm/rev
Depth of cut	0.5 to 1 mm

Fig1: CNC Lathe machine –SL 20

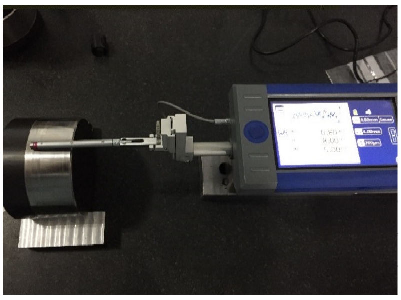

Fig 2: Taylor Hobson Surface Tester

Fig 3: Work piece Material (Bohler K110)

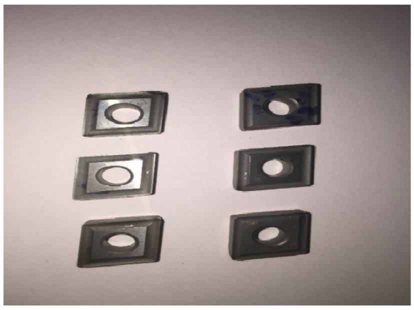

Fig 4: Inserts CNGA 120408 THM

TABLE 4: Readings for surface roughness (Dry Turning)

Experiment No	speed	feed	doc	Ra
1	105	0.20	0.50	0.400
2	80	0.35	0.75	0.685
3	130	0.35	1.00	0.710
4	130	0.50	0.50	1.420
5	105	0.35	1.00	0.960
6	130	0.50	1.00	1.420
7	130	0.35	0.75	0.650
8	80	0.35	0.50	0.450
9	105	0.50	1.00	1.700
10	130	0.50	0.75	1.380
11	130	0.20	0.50	0.280
12	80	0.50	0.50	1.800
13	130	0.20	1.00	0.330
14	105	0.35	0.50	0.810
15	80	0.20	1.00	0.700
16	80	0.35	1.00	0.950
17	130	0.35	0.50	0.500
18	130	0.20	0.75	0.300
19	105	0.20	0.75	0.450
20	105	0.50	0.75	1.490
21	80	0.20	0.50	0.500
22	105	0.50	0.50	1.300
23	80	0.20	0.75	0.560
24	80	0.50	1.00	1.860
25	105	0.20	1.00	0.440
26	80	0.50	0.75	1.820
27	105	0.35	0.75	1.400

Data pre-processing is normally required, since the range and unit in one data sequence may differ from others. It is also necessary when the sequence scatter range is too large, or when the directions of the target in the sequences are different. In this study, a linear normalization of the experimental results for surface roughness & tool wear were performed in the range between zero and one, which is also called the grey relational generation.
The transformation of S-N Ratio values from the original response values was the initial step

$$Type\ 2 : \left(\frac{S}{N}\right)_{LB} = -10\ \log_{10}\left\{\sum \frac{y_{ij}^{2}}{n}\right\}$$

Where Y_{ij} is the value of the response 'j' in the i^{th} experiment condition, with i=1, 2, 3…n; j = 1, 2…k and S2 are the sample mean and variance

Y_{ij} is normalized as Z_{ij} ($0 \le Z_{ij} \le 1$) by the following formula to avoid the effect of adopting different units and to reduce the variability.The normalized data processing for SR corresponding to lower-the-better criterion canbe expressed as:

$$Z_{ij} = \frac{max(y_{ij}; i = 1,2, \ldots.n) - y_{ij}}{max(y_{ij}; i = 1,2, \ldots.n) - min(y_{ij}; i = 1,2, \ldots.n)}$$

Where Zi (j) is the value after the grey relational generation, min *y*i (j) is the smallest value of *y*i(j) for the jth response, and the max *y*i (j) is the largest value of *y*i (j) for the *k*th response.
Basically, the larger normalized results correspond to the better performance and the best-normalized result should be equal to one. Next, the grey relational coefficient is calculated to express the relationship between the ideal (best) and actual normalized experimental results.
The grey relational coefficient can be calculated as:

$$\xi_i\,(K) = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \zeta\Delta_{max}}$$

$$\Delta_{min} = \underset{\forall_{j\,\in i}}{min}\;\underset{\forall_k}{min}\;\|y_{(0)}(k) - y_j\,(k)\|$$

Where $\Delta_{0i}(k)$is the deviation sequence of the reference sequence and comparability sequenceand y_j (k) denotes the comparability sequence. ζ is distinguishing or identified coefficient. The value of ζ is the smaller and the distinguished ability is the larger. ζ = 0.5 is generally used. After averaging the grey relational coefficients (Table 5), the grey relational grade can be expressed as

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} Wk\xi_i(k)$$

Table 5: Grey relational coefficients and grades

Expt No	speed	feed	doc	Ra	Normalised S/n Ratio	Grey RlnCoeff-Ra	TW	Normalised S/n Ratio	Grey RlnCoeff-TW	GRG	Ranking
1	105	0.2	0.5	0.4	0.1884	0.3812	0.1400	0.4561	0.4790	0.4301	25
2	80	0.35	0.75	0.685	0.4725	0.4866	0.1500	0.5015	0.5007	0.4937	19
3	130	0.35	1	0.71	0.4914	0.4957	0.3000	0.9575	0.9217	0.7087	6
4	130	0.5	0.5	1.42	0.8575	0.7782	0.1800	0.6214	0.5691	0.6736	9
5	105	0.35	1	0.96	0.6507	0.5887	0.2400	0.8107	0.7254	0.6571	11
6	130	0.5	1	1.42	0.8575	0.7782	0.3200	1.0000	1.0000	0.8891	1
7	130	0.35	0.75	0.65	0.4448	0.4738	0.2200	0.7535	0.6698	0.5718	15
8	80	0.35	0.5	0.45	0.2506	0.4002	0.1000	0.2347	0.3952	0.3977	27
9	105	0.5	1	1.7	0.9525	0.9132	0.2800	0.9121	0.8505	0.8819	2
10	130	0.5	0.75	1.38	0.8424	0.7603	0.2400	0.8107	0.7254	0.7428	4
11	130	0.2	0.5	0.28	0.0000	0.3333	0.1400	0.4561	0.4790	0.4061	26
12	80	0.5	0.5	1.8	0.9827	0.9665	0.0700	0.0000	0.3333	0.6499	12
13	130	0.2	1	0.33	0.0868	0.3538	0.2800	0.9121	0.8505	0.6022	13
14	105	0.35	0.5	0.81	0.5610	0.5325	0.1700	0.5838	0.5457	0.5391	16
15	80	0.2	1	0.7	0.4839	0.4921	0.1800	0.6214	0.5691	0.5306	18
16	80	0.35	1	0.95	0.6452	0.5849	0.2000	0.6908	0.6179	0.6014	14
17	130	0.35	0.5	0.5	0.3062	0.4188	0.1600	0.5439	0.5230	0.4709	22
18	130	0.2	0.75	0.3	0.0364	0.3416	0.2000	0.6908	0.6179	0.4797	21
19	105	0.2	0.75	0.45	0.2506	0.4002	0.1600	0.5439	0.5230	0.4616	23
20	105	0.5	0.75	1.49	0.8829	0.8102	0.2100	0.7229	0.6434	0.7268	5
21	80	0.2	0.5	0.5	0.3062	0.4188	0.1400	0.4561	0.4790	0.4489	24
22	105	0.5	0.5	1.3	0.8108	0.7255	0.1900	0.6570	0.5931	0.6593	10
23	80	0.2	0.75	0.56	0.3661	0.4409	0.1600	0.5439	0.5230	0.4820	20
24	80	0.5	1	1.86	1.0000	1.0000	0.1700	0.5838	0.5457	0.7729	3
25	105	0.2	1	0.44	0.2387	0.3964	0.2200	0.7535	0.6698	0.5331	17
26	80	0.5	0.75	1.82	0.9885	0.9776	0.1200	0.3546	0.4365	0.7070	7
27	105	0.35	0.75	1.4	0.8500	0.7692	0.2100	0.7229	0.6434	0.7063	8

Where, γ_i is the grey relational grade for the j^{th} experiment and k is the number of performance characteristics. Here $W_k$denotes the normalized weight factor and taken as 1. The grey relational grade $\gamma_i$represents the level of correlation between the reference sequence and the comparability sequence. If the two sequences are identical, then the value of grey relational grade is equal to 1. The high relational grade implies that the corresponding parameter combination is closer to the optimal. The grey relational grade also indicates the degree of influence that the comparability sequence could explain over the reference sequence. The higher grey relational grade represents that the corresponding experimental result (Table 4, Experiment number 6) is closer to the ideally normalized value. In other words, optimization of the complicated multiple performance characteristics can be converted into optimization of a single grey relational grade. Because of the experimental design it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels (Table 6). Basically, the larger the grey relational grade the better is the multiple performance characteristics. However, the relative importance among the

machining parameters for the multiple performance characteristics still needs to be known so that the optimal combinations of the machining parameter levels can be determined more accurately.
From Table 6 and Fig. 5, it is clearly known thatsecond level of speed, third level of feed and third levelof depth of cut are the optimal combination of processparameters for multiple performance characteristics.

Table 6: Grey relational grades at different levels

Parameters	Level I	Level II	Level III	Max-Min	Rank
speed (A)	0.5649	0.6217	0.6161	0.0512	2
feed (B)	0.486	0.5718	0.7448	-0.2588	1
Doc (C)	0.5195	0.5969	0.6863	-0.1668	3

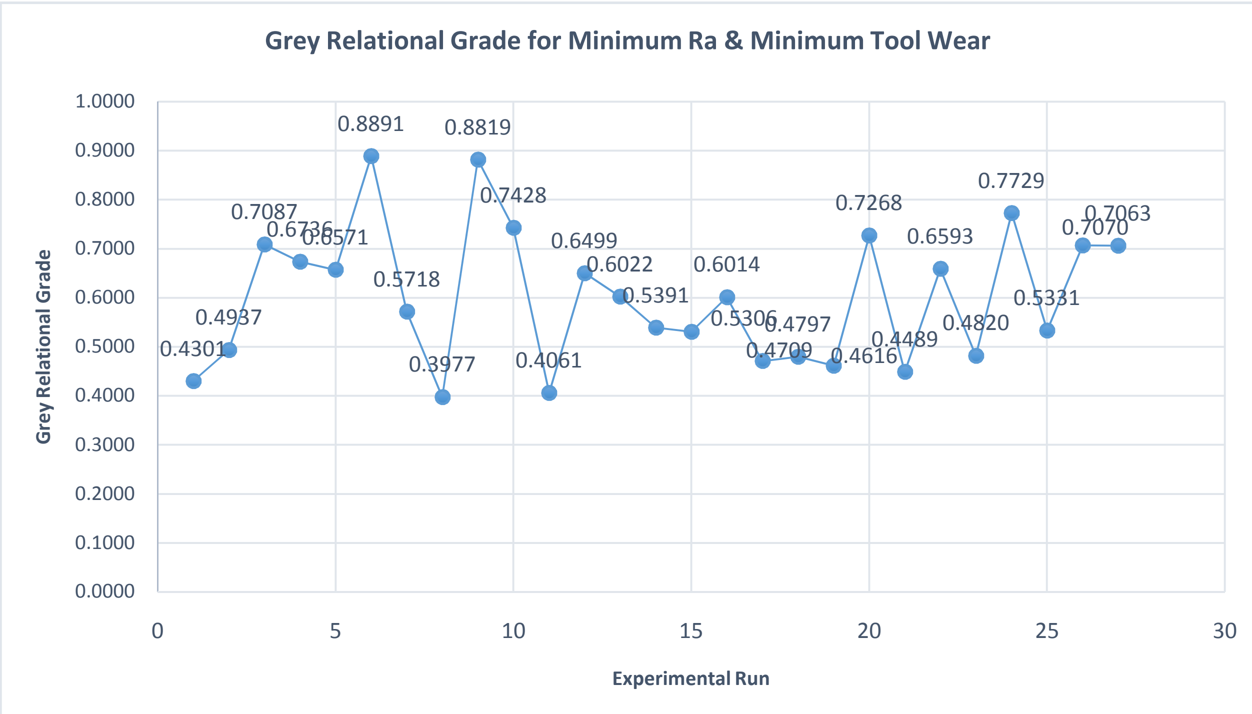

Fig. 5: GRG of multiple performances characteristic

Confirmation of tests

After identifying the optimal process parameters, the confirmation test is to be conducted to validate theanalysis. In the confirmation test, an experiment hasbeen conducted with optimal process parameterssettings. The optimal parametric combination for achieving minimum surface roughness and tool wear by using grey relational analysis is A2B3C3. Cutting speed of 105 m/min, Feed 0.5 mm/rev, depth of cut 1.0 mm. Atthe optimal setting, the response values from theconfirmation experiments are surface roughness is1.25 and tool wear is 0.20.

7. CONCLUSION

In this study, Bohler K 110 is used, whichis a costly material and has got peculiar characteristicswhich make it difficult to machine. Therefore, theselections of optimal parameters are important tominimize the higher unit cost per machined part by hard part turning.

In this work, Greyrelational analysis has been used to provide an efficientdesign of experiment technique to obtain simple, systematic and efficient methodology for theoptimization of the process parameters at high speedmachining.The application of Greyrelational analysis directly integrates the multiplequality characteristics (Surface Roughness, Tool wear) into a singleperformance characteristic called grey relationalgrade. The grade obtained for each experiment canimmediately reflect the actual turning results in termsof quality of surface, cutting force and tool wear.The experimental results show that the optimalcutting parameters are high cutting speed 105 m/min,lower feed 0.5 mm/rev and lower depth of cut 1.0mm, gives the lower surfaceroughness (SR) and tool wear (TW) togetherwithin the range of experiments based on the averagegrey relational grade.Thus it may be concluded that themultiple performance characteristics of the Bohler K 110 turning process such as surface roughness &tool wear and are improved together byusing this approach.

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